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HYDROLOGIC TRACER STUDIES CONDUCTED AUGUST 20-25, 1962 NEAR CAPE THOMPSON, ALASKA

By

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Information pertaining to hydrologic tracer tests carried out at the Project Chariot site near Cape Thompson, Alaska, August 20-25, 1962 is attached. Several field studies utilizing cesium-137, iodine-131, strontium-85 and in-close fallout material from Sedan event were conducted. Transport of the radioactive tracers was studied under varying conditions including overland transport on ten micro-plots, infiltration through soil using a seepage pit located in a sloping hillside, and by observing the sediment wave in a small stream. These studies were conducted in an attempt to relate distribution coefficients determined in the laboratory to those obtained under field conditions.

The plots were chosen to represent a variety of micro drainage patterns, vegetative cover and soil types. Diagrams of the plots are given in figures 11-20 at the end of the text. The edges of the plots were defined by the use of 1 x 6 inch boards wrapped with polyethylene sheeting and buried a sufficient depth in the ground to isolate the plot from surrounding area and to control the run-off of applied water. First the tracer material was mixed with dry sifted soil of the same type as found in the vicinity of the study plot and then uniformly applied to the plot. Water from Snowbank Creek or its tributaries was sprayed on the study plot to simulate rain, until the ground was saturated and runoff began. A portable gasoline powered water pump and water hoses with spray nozzles were used to apply the water from the creeks to the plots. These waters had low suspended and dissolved solids. Chemical reactions of the water used, although not identical to rainwater, should be comparable.

Samples of soil and runoff from the plots were collected in polyethylene containers after an application of water. After completion of the field work, all samples were transported to the Denver Q. W. Lab where the relative amounts of radioactivity were measured for all solid and liquid samples.

The distribution and quantity of water applied to each plot was measured using fifty milliliter beakers arranged in a regular pattern on the plot. The depth of water in each beaker was measured after an application of water. The locations where the beakers were placed on each plot are indicated on the diagrams by the numbered circles. The average applied depths of water were calculated for several plots by the Thiessen Mean (Wisler) graphical method and by averaging the measured values for a plot. Results obtained were nearly the same so only the arithmetic averages of the depths of water in the 50 ml beakers for each plot are reported.

Having determined the volume of water applied to a plot, a reactive weight of soil was needed to calculate distribution coefficients. For a first approximation, the top centimeter of soil in each plot was considered to have reacted with the radioactive material used to seed the plots and the water applied. Areas of the plots were determined and the weight of the soil in the top centimeter of each plot was calculated. The value thus obtained was used to calculate distribution coefficients. The runoff collected from the plots times its concentration of the tracer gave the amount of the tracer contained in the liquid phase. Knowing the concentration and weight of the tracer applied, the total radioactivity applied was calculated. Distribution coefficients were calculated using the following equation:

$$K_d = \frac{\text{Percent solid}}{\text{Percent liquid}} \cdot \frac{V}{M}$$

where K_d is the distribution coefficient for the tracer used, percent solid is the percent of radioactivity applied to the plot remaining on the solid, percent liquid is the percent of radioactivity in the total quantity of liquid applied, V is the volume in milliliters of liquid applied, and M is the mass in grams of the solids that were considered to have reacted.

Tables 1-3 contain information concerning plot sizes, the tracers used, the specific activities of the tracers, the weights and volumes of the solids and liquids respectively, considered to have reacted, and the distribution coefficients calculated for these variables on each plot.

Several experiments were run in the laboratory to relate distribution coefficients obtained during field studies (table 3) with those obtained in laboratory studies (tables 4 and 5). Triplicate portions of the radioactive spiked soil were equilibrated with water and the radioactivity extracted by the liquid was determined. With new portions of water, this procedure was repeated several more times. Water from Snowbank Creek was used for these multiple equilibration experiments on the laboratory samples to duplicate, as much as possible, the reacting constituents which existed in the field. The sum of the counts removed was plotted vs. number of equilibrations for cesium and strontium, in figures 1 and 2. The curves show a gradual reduction in the amount of radioactivity removed from the solid phase with successive equilibrations.

Radioactivity present in the runoff waters collected from the various cesium plots averaged less than the minimum detection level of 4 cpm/ml so that little comparison is possible between field and laboratory data. Distribution coefficients obtained from the multiple equilibration study for cesium ranged from 61,000 to 340,000. Runoff samples obtained from plots with the V/M ratio used in the calculations based on a 1 cm reacting depth of soil as a first approximation gave a minimum distribution coefficient of 6,300 for cesium. If the lab and field data are correlative, the V/M ratio used to calculate field distribution coefficients should have been in the 0.25-2.0 millimeter reacting depth of soil rather than one centimeter

Table 1.--Data from micro-plot tracer studies conducted near Cape Thompson, Alaska.

Plot number	Tracer	Weight of diluted tracer applied (g)	Plot area (cm^2)	Depth of water applied to plot (cm)
63 ABJ 105	cesium-137	1,800	11,750	3.89 1.55
63 ABJ 106	cesium-137	1,800	10,900	3.33 1.70
63 ABJ 107	cesium-137	1,800	6,350	3.38 2.90
63 ABJ 109	iodine-131	900	3,720	3.71
63 ABJ 110	iodine-131	1,800	3,720	3.53
63 ABJ 111	strontium-85	1,800	4,530	4.95
63 ABJ 112	strontium-85	1,500	6,600	2.49 2.46
63 ABJ 113	Sedan fallout	1,350	31,400	2.59 2.26 2.08 2.21 1.88 1.73 1.63
63 ABJ 114	Sedan fallout	1,350	22,100	2.16 2.24 2.67 1.73 1.32 1.93 2.64
63 ABJ 115	Sedan fallout	1,350	2,790	3.33 .64
63 ABJ 116	Sedan fallout	1,350	--	--
63 ABJ 117	Sedan fallout	2,500	--	--

Table 2.--Additional data from micro-plot tracer studies conducted near Cape Thompson, Alaska.

Plot number	Specific activity of tracer (cpm/g)	Volume of water applied to plot (cm^3)	Radioactivity in runoff water (cpm/ml)	Weight of soil per cm of depth in plot (g)
63 ABJ 105	768,000	45,600 18,200	N.D. < 4	31,000
63 ABJ 106	467,000	36,300 18,600	< 4 < 4	29,000
63 ABJ 107	492,000	21,100 18,100	< 4 < 4	16,500
63 ABJ 109	222,000	13,800	26	10,000
63 ABJ 110	222,000	13,100	38	10,000
63 ABJ 111	203,000	22,400	150	12,000
63 ABJ 112	145,000	16,500 16,200	200 112	17,500
63 ABJ 113	23,300	81,300 70,900 65,300 60,300 59,000 54,300 51,200	7 < 7 < 7 < 7 < 7 < 7 < 7	83,000
63 ABJ 114	23,300	47,700 49,500 59,000 38,200 20,200 42,600 58,300	< 7 < 7 < 7 < 7 < 7 < 7 < 7	58,500
63 ABJ 115	23,300	9,300 1,800	< 7 < 7	7,500
63 ABJ 116	23,300	--	--	--
63 ABJ 117	23,300	--	--	--

Table 3.--Calculated distribution coefficients and radiochemical data for studies near Cape Thompson, Alaska.

Plot number	Tracer	Total radiotracer applied to plot (x 10^7 cpm)	Total radioactivity in the water (x 10^4 cpm)	Radioactivity		Kd
				percent in solid	percent in liquid	
63 ABJ 105	cesium-137	140	26	99.98	0.02	10,300
63 ABJ 106	cesium-137	84	22	99.97	.03	6,300
63 ABJ 107	cesium-137	89	16	99.98	.02	11,900
63 ABJ 109	iodine-131	20	36	99.82	.18	770
63 ABJ 110	iodine-131	40	50	99.87	.13	1,000
63 ABJ 111	strontium-85	37	340	99.07	.93	200
63 ABJ 112	strontium-85	22	510	97.63	2.37	77
63 ABJ 113	Sedan fallout	3.1	320	88.49	11.51	41
63 ABJ 114	Sedan fallout	3.1	230	91.99	8.01	62
63 ABJ 115	Sedan fallout	3.1	7.7	99.75	.25	590

Table 4.--Multiple equilibration distribution coefficients for cesium, plot soil, and water from Snowbank Creek

Sample	Equilibration 1	2	3	4	5	$\frac{V}{M}$
106-5	140,000	340,000	130,000	330,000	230,000	110
107-0	61,000	160,000	160,000	210,000	220,000	226

Table 5.--Multiple equilibration distribution coefficients for strontium, plot soil, and water from Snowbank Creek

Sample	Equilibration 1	2	3	4	5	$\frac{V}{M}$
111	1,500	4,000	10,000	18,000	46,000	96
111-4	1,500	3,300	6,500	18,000	21,000	82
112	2,800	4,200	6,100	8,700	13,000	95

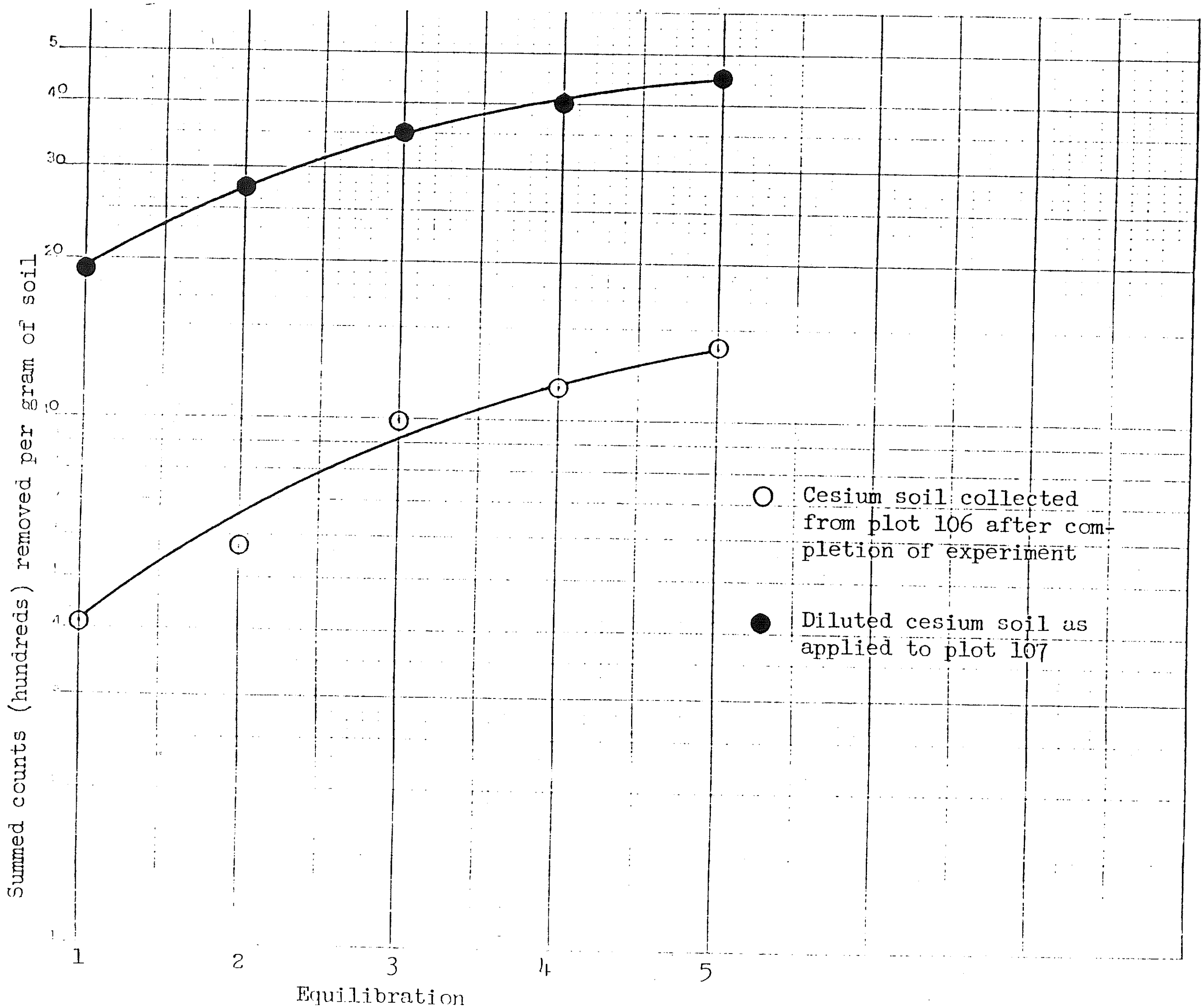

Figure 1.--Summed counts removed from cesium soil by successive equilibrations.

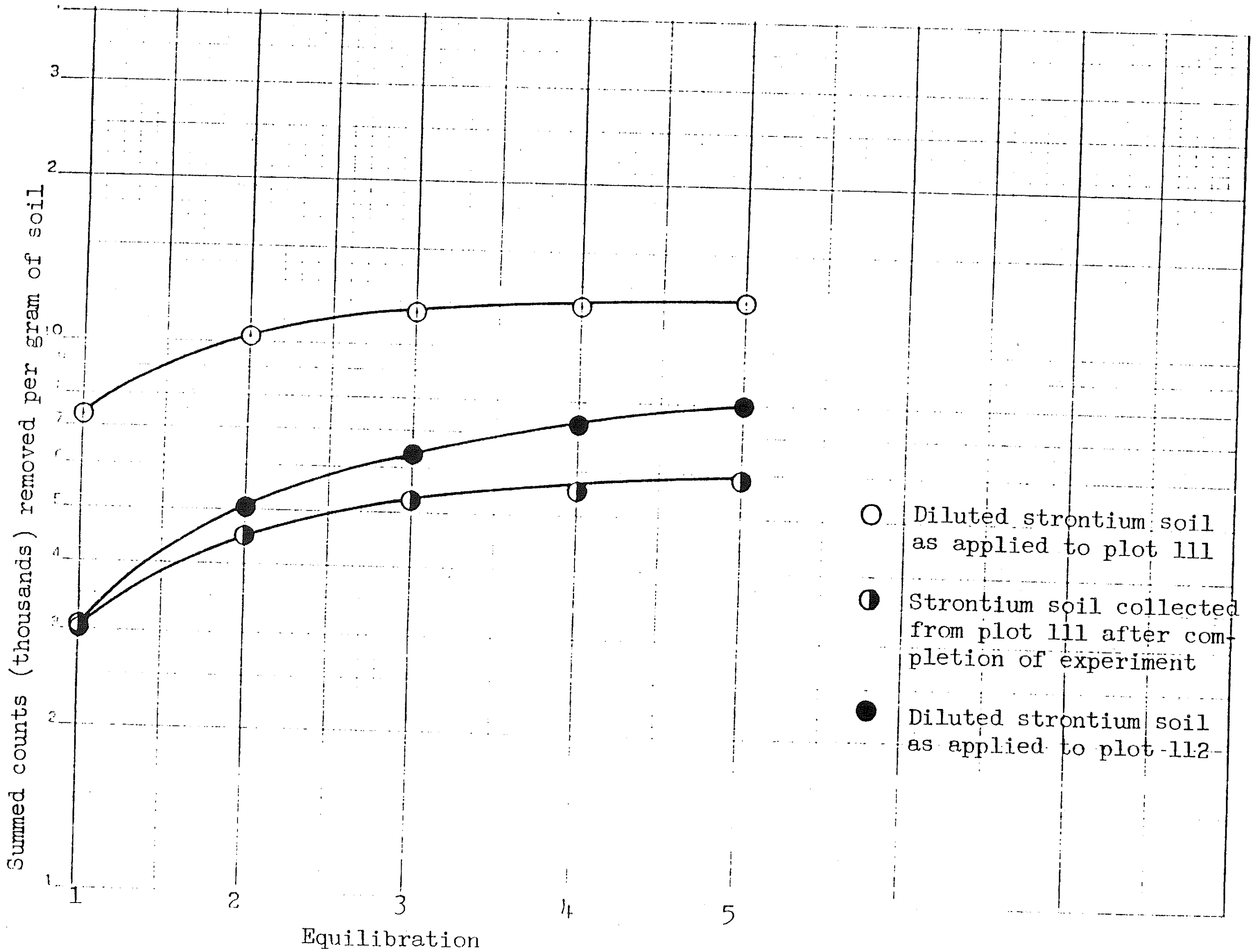

Figure 2.--Summed counts removed from strontium soil by successive equilibrations

as used. Distribution coefficients calculated using several different depths of reactive soil are given below. Cesium would appear to have

Plot number	Depth of reacting soil (cm)			
	1.0	0.2	0.1	0.04
63 ABJ 106	6,300	32,000	64,000	160,000
63 ABJ 107	12,000	60,000	120,000	300,000

been limited in its transport ability by the nature of the probable fallout material. The transport characteristics of this probable fallout material as sediment rather than mechanisms involving the solution of cesium seems to be the dominant factor.

Runoff collected from the plots seeded with strontium-85 contained a maximum of 200 cpm/ml which was higher than the levels obtained for runoff samples from the cesium plots. A comparison of the radioactivity levels observed in the field runoff solutions and the laboratory equilibration solutions indicate also a more shallow reactive soil depth than was assumed during the first approximation. Different reactive soil depths for strontium plots are compared below.

Plot number	Depth of reacting soil (cm)			
	1.0	0.2	0.1	0.04
63 ABJ 111	200	1,000	2,000	5,000
63 ABJ 112	77	385	790	1,900

The strontium distribution coefficient data indicates essentially the same reactive depth as the cesium data, i.e., between 0.25-2.0 mm of soil reacted with the tracer and water to give the concentrations observed in the effluent water.

Distribution coefficient values obtained for iodine-131 on plots 109 and 110 were extremely high and not in accord with expected values. However, the high values obtained in the field were confirmed by lab tests using the same soil mixture and water from Snowbank Creek. The high values are not completely understood but may be due to several variations in methodology. Generally, iodine exhibits a higher uptake by soils containing organic material than for purely inorganic soils. Application of the radioiodine tracer to both plots 109 and 110 was performed in the same manner as the other isotopes, i.e., radiotracer in soluble form was initially diluted by mixing with pulverized soil and the dried mixture was then applied to the plots. Organic material was present in the pulverized soil used for dilution, probably in sufficient quantity to retard the release of soluble iodine-131 to the plots. The experiment is rather inconclusive except in showing very large retentive properties of tundra soil.

An eighteen hour infiltration experiment using Sedan event fallout material was also conducted. A small pit was dug to an approximate depth of 25 cm (Plot 63 ABJ 116, figure 3) into a sloping hillside. Three pounds of Sedan event fallout material were placed in the pit and sufficient water was added to fill the hole within two inches of the top. The mixture was then agitated to disperse the fallout throughout the liquid. A small ditch was dug perpendicular to the direction of slope of the hillside and 84 cm from the lower edge of the hole. Seepage water was collected in plastic bottles at 15 minute intervals for 4 hours and then one additional integrated sample was collected overnight at the location as shown in figure 3 . A histogram of the count rates, figure 4, was plotted for the various seepage samples. The four peaks in figure 4 were obtained from samples collected directly after four water additions were made to the slurry in the hole. More rapid subsequent flow was obtained each of the four times the hole was refilled. Perhaps some flow occurred through the relatively porous upper six inches of the soil profile to account for the rise of radioactivity. However, the maximum count rate observed in the seepage was only 14 cpm for a 2 ml aliquot. When compared to the

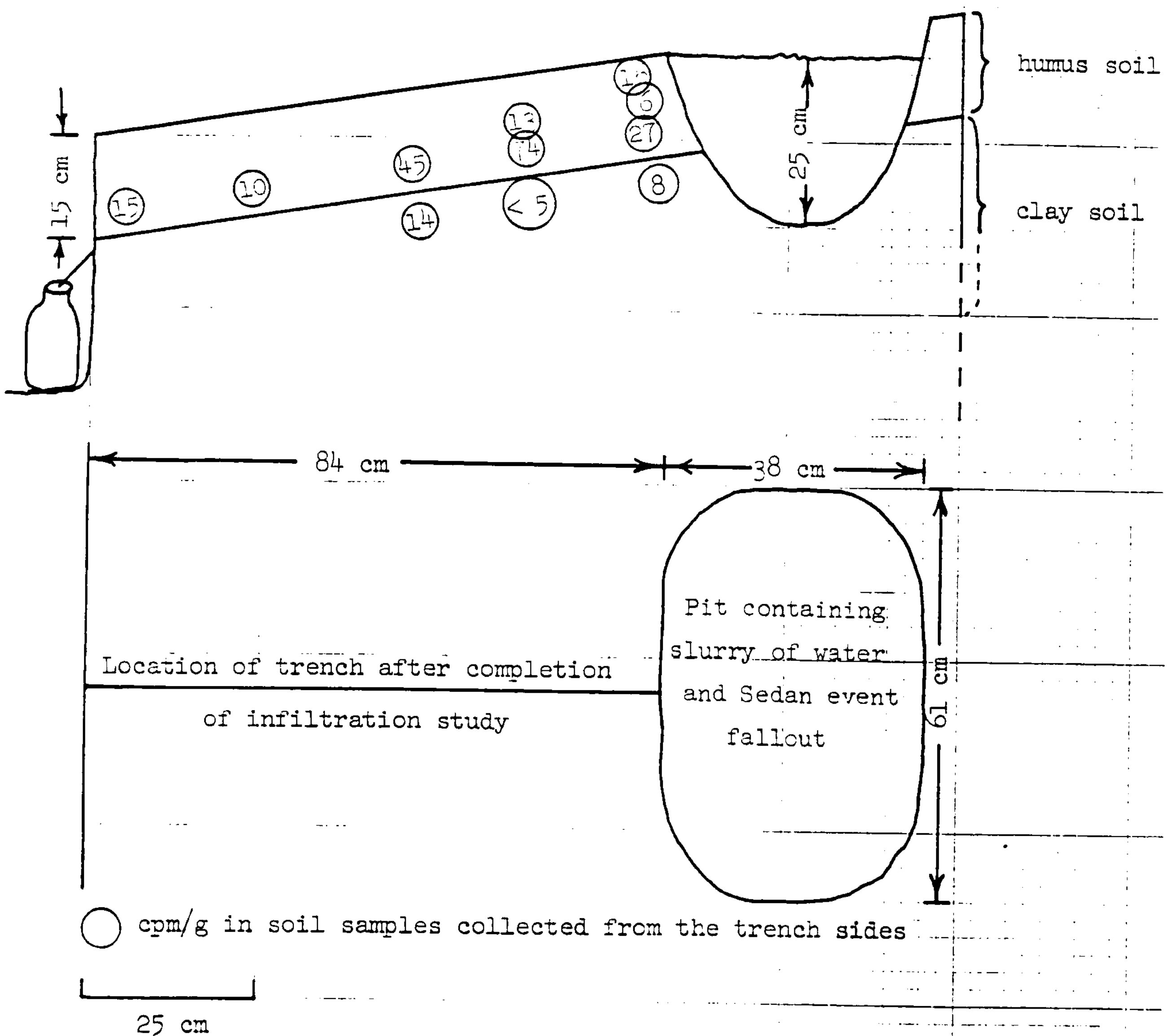

Figure 3.--Plot 63 ABJ 116. Cross section and plan diagrams of an infiltration study using Sedan event fallout as tracer. The study was run on a hillside with the approximate locations of the soil horizons as indicated. Soil samples were collected at the locations shown in cross section after the infiltration study had been completed.

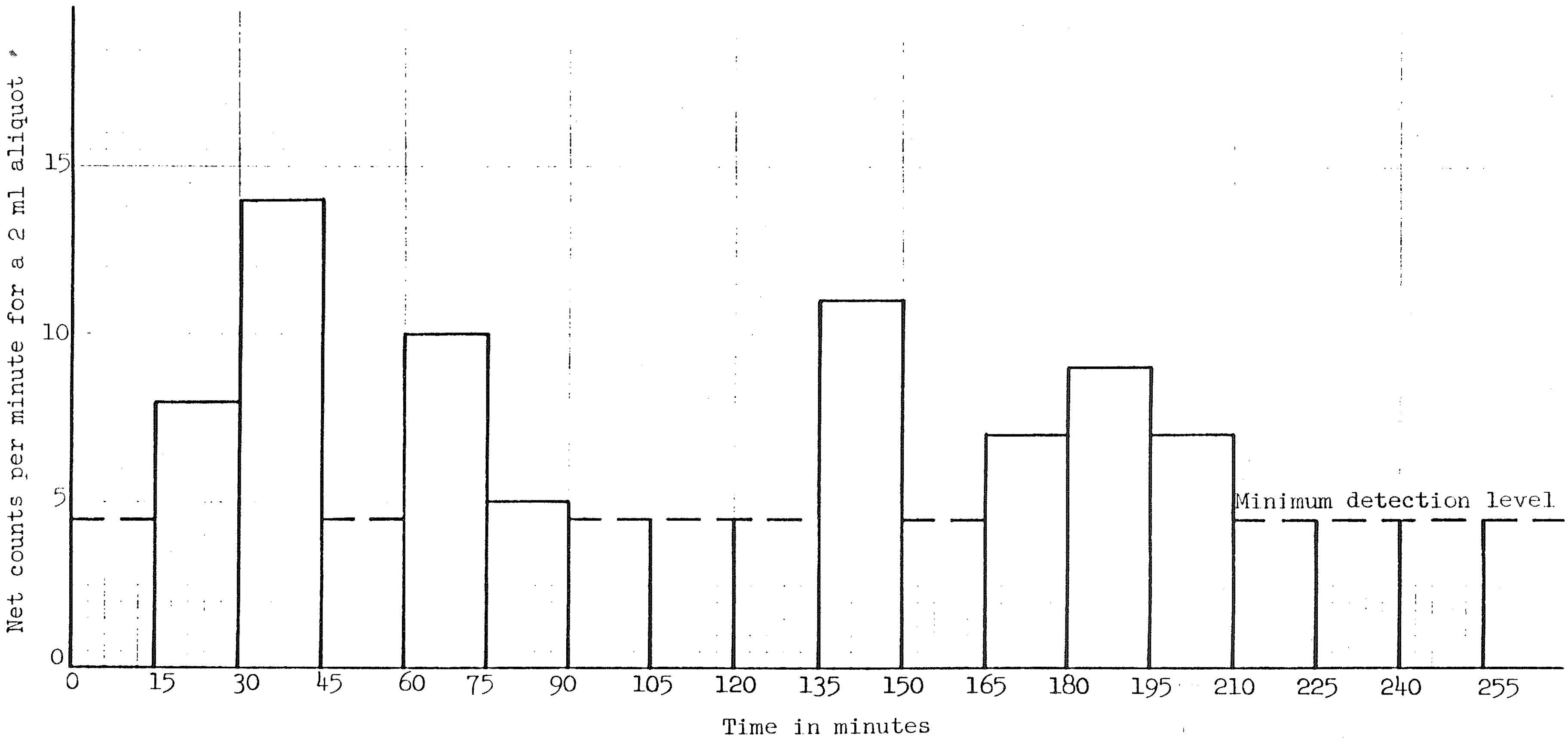

Figure 4.--Radioactivity of seepage samples from an infiltration study conducted near Cape Thompson, Alaska.

23,260 cpm/g count rate of the original Sedan fallout material, the 14 cpm observed in the 2 ml aliquot could possibly have resulted from air contamination of the samples or of the area at time of seeding the pit. If contamination did occur, however, the total radioactivity transported from the hole would be less than that indicated by the 14 cpm/2 ml maximum observed in the samples. The count rate of the mud remaining in the hole after the experiment was diminished to 11,442 cpm/g. This count rate reduction resulted from dilution of the fallout material with mud from the sides of the hole when the material was stirred. In any case, the total amount of radioactivity transported from the pit to the ditch was a very small fraction of the total available for transport.

After the experiment, a trench was dug exposing the soil profile from the bottom of the pit to the collection ditch. Soil samples were taken at the points indicated in figure 3 and the count rates obtained for the samples from the various locations were determined. The highest concentration of radioactivity was found at the contact of the humus soil and the clay. Apparently the water leaving the pit flowed downward through the relatively porous humus until it reached the humus-clay contact. At this point the majority of the migrating water flowed along the contact zone as indicated by the count rates obtained from soil samples taken in the cross section. Count rates obtained for the soil samples collected at the various locations in the cross section are shown in figure 3. Again, although care was exercised, no assurance can be given that contamination did not occur during the trenching of the cross section which could account for the greater than background readings obtained.

On a small tributary of Snowbank Creek, the sediment wave of an introduced quantity of Sedan event fallout was studied. The reach chosen was of fairly uniform slope and cross section and had a flow rate of approximately 60 liters/minute. The flow rate was determined by catching the total discharge of the stream over a small waterfall in a bucket for measured lengths of time.

The stream was measured off into twenty foot reaches. After samplers were located at the 20, 40 and 60 foot stations, a slurry containing 5 lbs. 7 oz. of Sedan event fallout was introduced as a single injection slug at the zero station of the test reach. Simultaneous samples of water were collected at exactly one minute intervals in one ounce polyethylene bottles at the 20, 40 and 60 foot sampling points. Fifteen minutes after introduction of the fallout material, the stream bottom at the point of introduction was vigorously agitated to disperse any of the fallout which had been adsorbed or settled on the stream bottom. Sampling was continued until a total time of 20 minutes had elapsed from the time of the initial introduction.

When the samples were received in Denver, 2 ml aliquots of each sample were removed after agitating the samples to insure dispersion of any settled sediment. The aliquots were counted using a single channel gamma spectrometer with wide open window. Count rates were recorded and a histogram was drawn plotting counts per minute/ml vs. time for each of the 3 different sampling stations, figures 5-7. A curve was fitted from the histogram data and the maximum count rate of the two concentration peaks at each of the three sampling stations were plotted as counts per minute/milliliter vs. distance, in feet, downstream from the point of introduction, (fig. 8). Maximum concentrations of radioactivity with distance from point of introduction in this experiment was compared with another experiment run on the Mohawk River (Simpson, E. S., et al). Data of the two studies is given in table 6. A diagram showing the maximum concentration with distances obtained on the Mohawk River to Tributary 3, Snowbank Creek is attached (figure 9).

Sedan event fallout, the tracer material used in Tributary 3, Snowbank Creek near Cape Thompson, was fine grained material collected

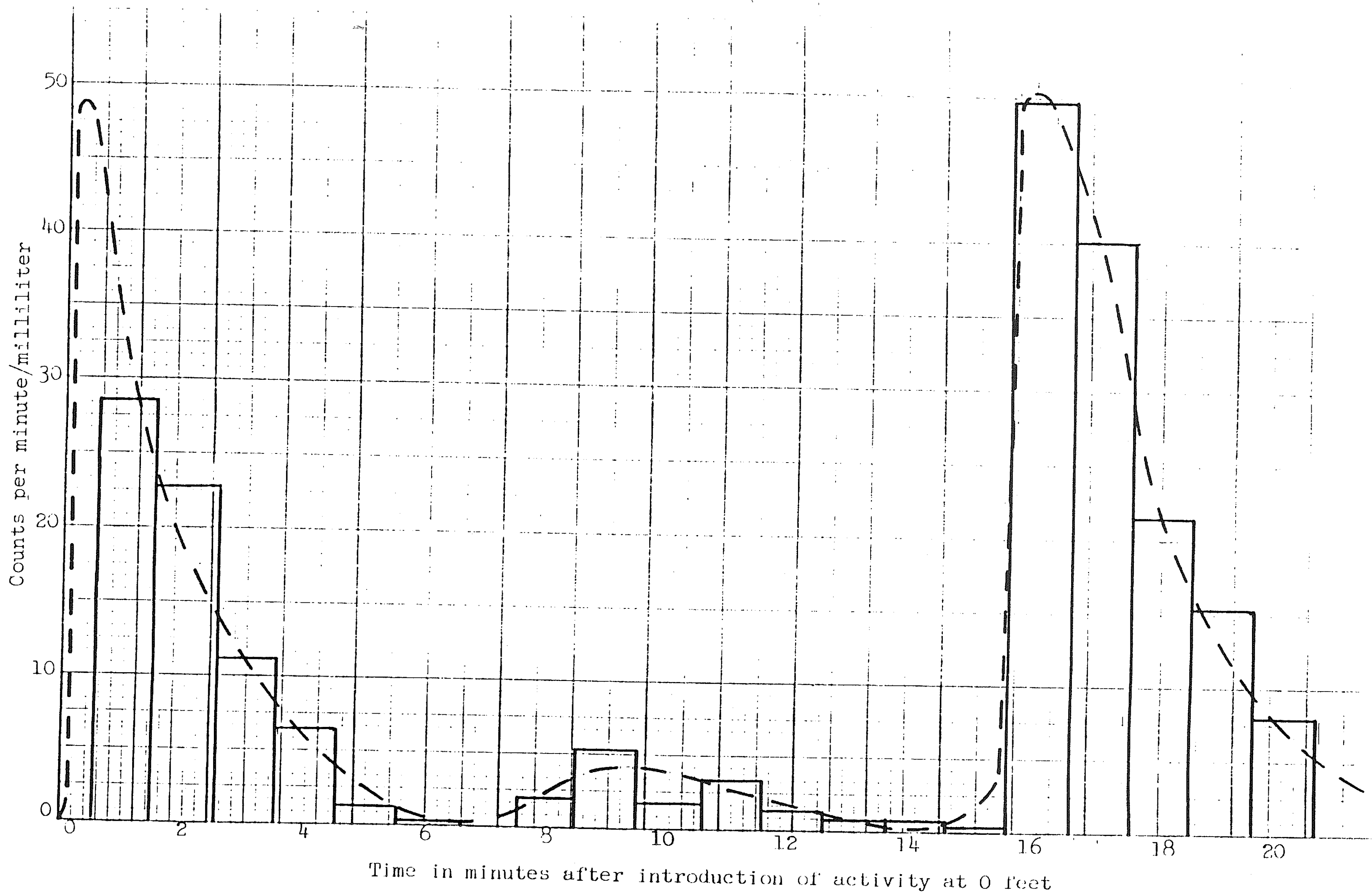

Figure 5.--Concentration vs. time at 20 foot sampling point in stream tracer study near Cape Thompson, Alaska

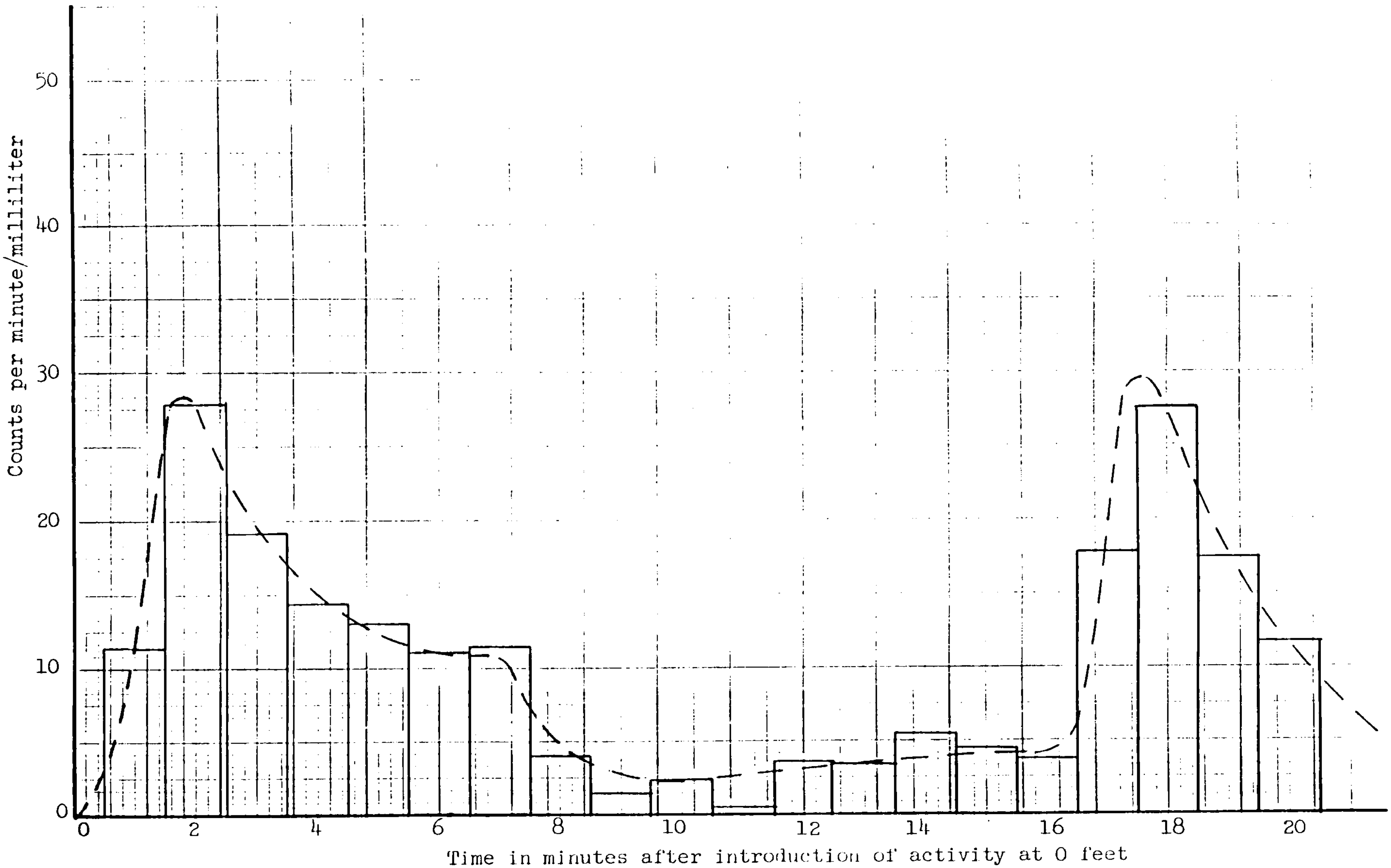

Figure 6.--Concentration vs. time at 40 foot sampling point in stream tracer study near Cape Thompson, Alaska

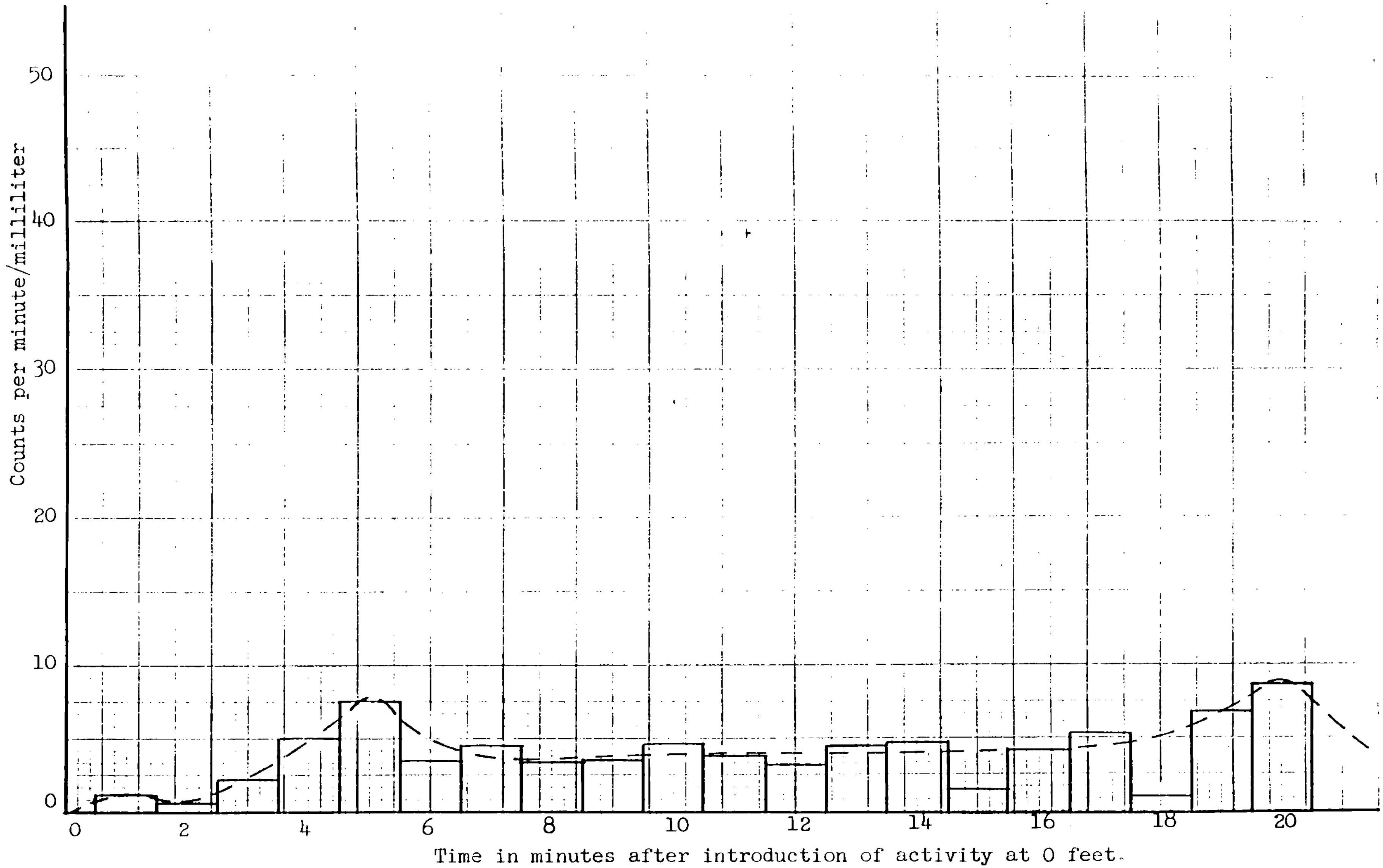

Figure 7.--Concentration vs. time at 60 foot sampling point in stream tracer study near Cape Thompson, Alaska

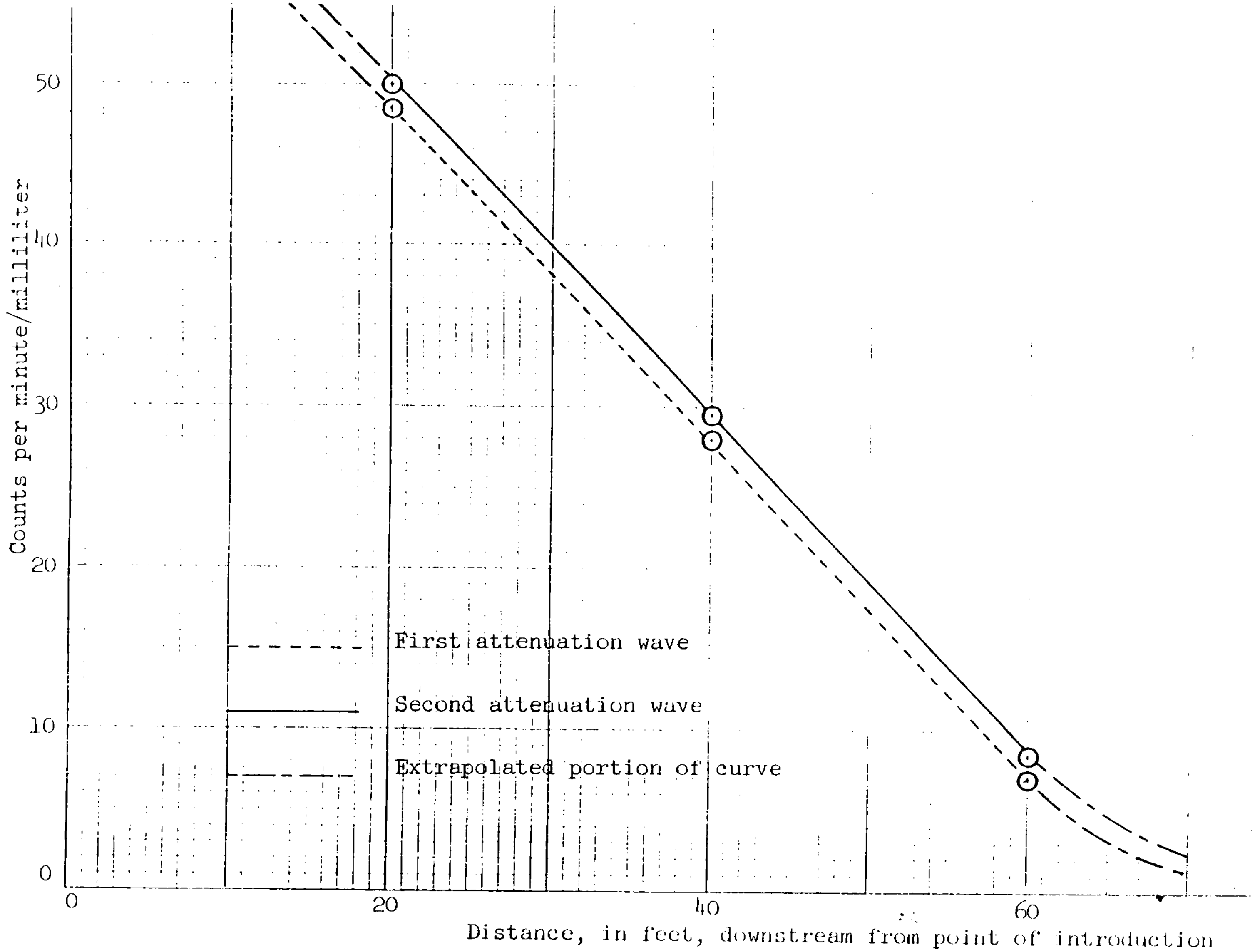

Figure 8.--Attenuation of Sedan event fallout activity in Tributary 3 of Snowbank Creek as a function of distance from point of introduction

Table 6.--Comparison of tracer dispersion studies conducted in the Mohawk River at Knolls Atomic Power Laboratory, N. Y., and tributary 3 of Snowbank Creek, near Cape Thompson, Alaska

	Mohawk River	Tributary 3, Snowbank Creek
Water temperature	76°F	≅40°F
Tracer used	Phosphorous-32	Sedan event fallout
Quantity of tracer used	3.3 curies	5 lbs. 7 oz.
Form in which tracer was introduced	Solution of KH_2PO_4 at 200 gpm rate	Water slurry introduced as a slug
Time required for introduction	1 hour, 9 minutes	3 seconds
Tracer temperature	68°F	≅40°F
Discharge rate of water	≅2,200 cfs	≅.03 cfs
Area of a cross section	≅14,000 ft^2	≅0.1 ft^2
Width of stream	≅1,000 ft.	≅1 ft
Average velocity of water flow	≅9.4 ft/min	≅18 ft/min
Distance required for 10 fold dilution of radioactivity	330 ft	≅44 feet

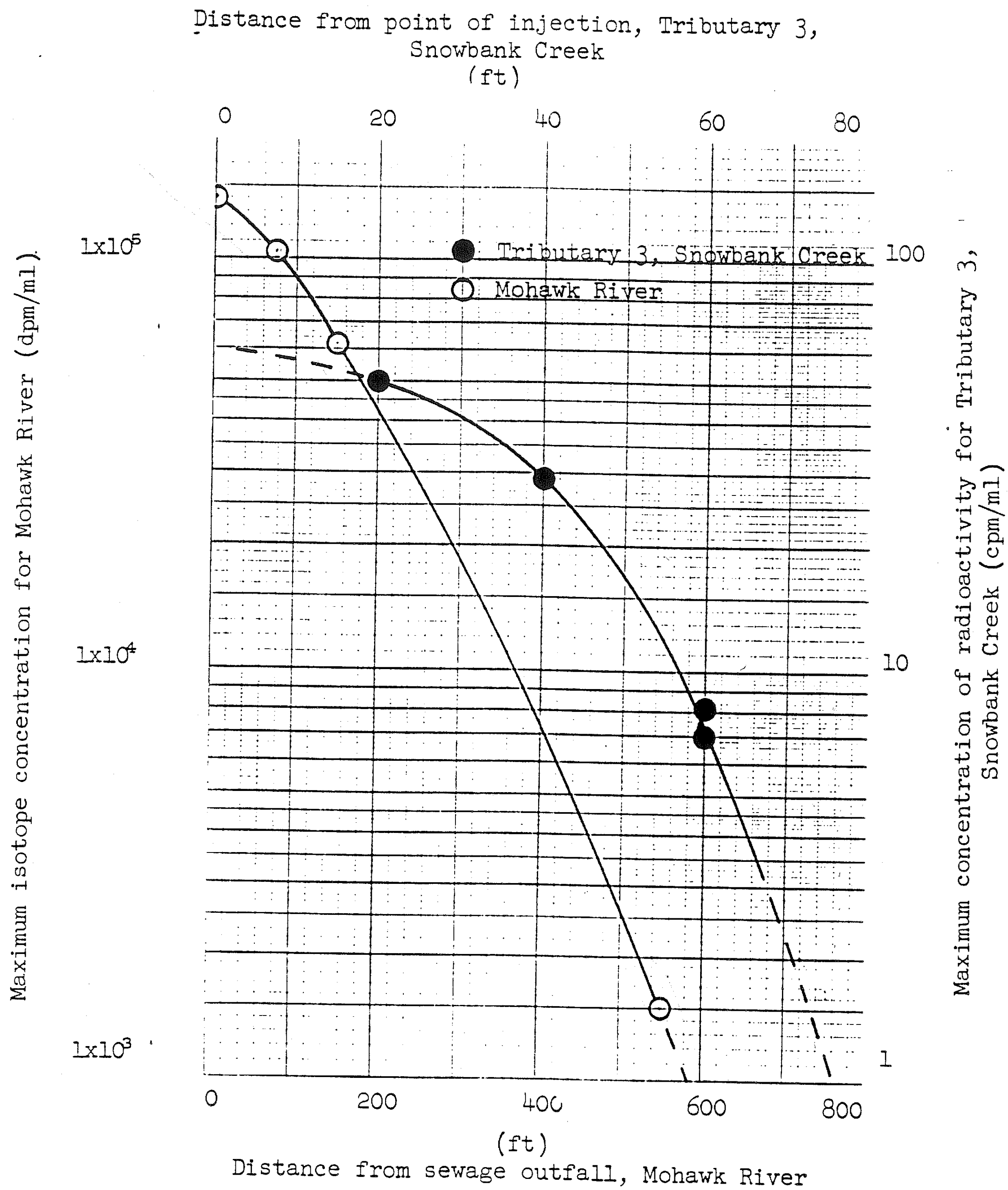

Figure 9.--Comparison of the maximum concentrations with distance of a dissolved phosphate tracer, Mohawk River at Knolls Atomic Power Laboratory, N. Y., and Sedan event fall-out, Tributary 3, Snowbank Creek near Cape Thompson, Alaska.

one mile from ground zero of the Sedan event. The radioactivity was due primarily to cationic constituents from the fission trigger and neutron activation occurring at the time of detonation. The radioactive tracer was already on this sediment prior to introduction in the stream. In the Mohawk River study, the tracer was soluble radioactive phosphate in the form of potassium dihydrogen phosphate with considerable carrier phosphate to minimize phosphate adsorption.

In spite of gross differences as to type and character of the tracers, definite similarities in the reduction of maximum concentrations were observed. Seemingly, after a sufficient distance has been traveled, which will depend upon the physical characteristics of the stream, a fairly homogeneous distribution of the radioisotope in the water-sediment mixture is obtained. Thereafter, the attenuation characteristics in a stream are quite similar, perhaps not only in both tests but in most streams due to velocity effects.

Sedan event fallout was also used on two plots 63 ABJ 113 and 63 ABJ 114 (figures 18 and 19). Plot 63 ABJ 113 was chosen to represent a micro drainage area that would drain an area approximately 150 cm x 205 cm. Only the upper one third of the plot was seeded with fallout and samples of runoff were collected where the drainage left the plot, see figure 18. Plot 63 ABJ 114 was a plot approximately 150 cm x 150 cm representing interior drainage. The entire plot was seeded with Sedan event fallout and water was then repeatedly applied to the plot. Runoff which collected in the interior of the plot was sampled after each application of water. Plot 63 ABJ 114 was chosen to represent the upper third of 63 ABJ 113 without drainage.

Both plots contained large amounts of moss and humus soil. The levels of radioactivity measured in the runoff samples collected from both plots were very close to the background level of 479 counts per minute obtained under the conditions of counting.

A graph of the radioactivity levels obtained from each 2 ml sample collected from both plots shows that all but two readings were within 2 standard deviations of the background readings, (figure 10). Little radioactivity was present in any of the runoff samples collected.

One additional plot was tested with Sedan event fallout. This was plot 63 ABJ 115 located on rocky barren soil, see figure 20. Size of the plot was 47.5 cm by 61 cm. Two samples of run-off were collected from Plot 63 ABJ 115. Neither contained significant counts above background.

Little radioactivity was transported in dissolved form from a test plot with an almost complete disregard of the type of cover on the plots chosen. The character of the fallout, not of the plots seemed to govern the levels of radioactivity found. In the case of Sedan fallout plots, as with the others, if there was no movement of particulate material there was no transport of radioactivity.

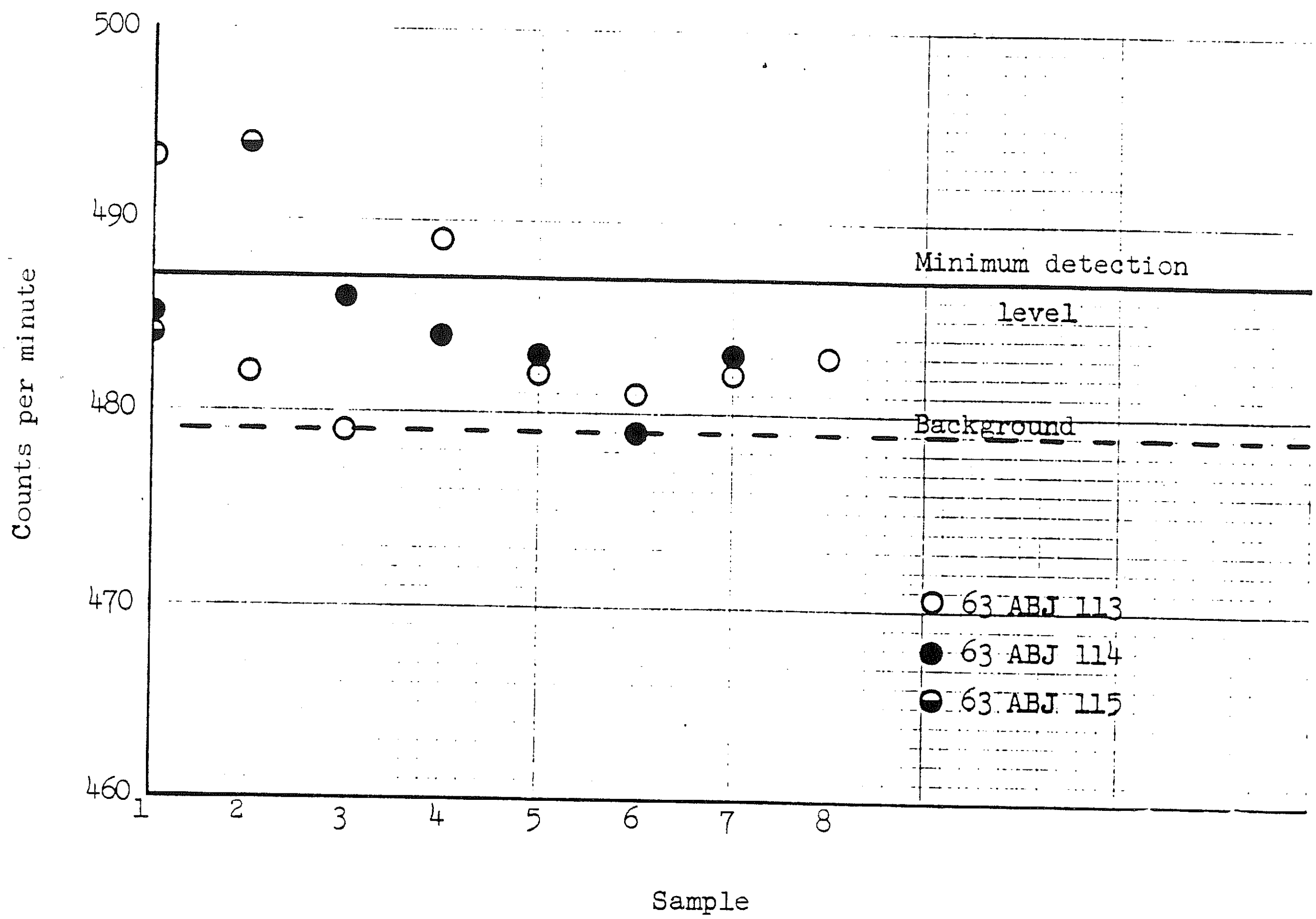

Figure 10.--Levels of radioactivity for 2 ml aliquots of runoff collected from micro-plots 63 ABJ 113, 63 ABJ 114 and 63 ABJ 115 near Cape Thompson, Alaska

References cited

Simpson, E. A., Beetem, W. A., Ruggles, F. H. Jr., and others, SO-45 UC-70 Radioactive Waste (TID-4500, 14th Edition) Hydrologic and Tracer Studies in Mohawk River at Knolls Atomic Power Laboratory USGS (1959). p. 159.

Wisler, C. O., and Brater, E. F. (1959) Hydrology, John Wiley and Sons, New York, p. 81-82.

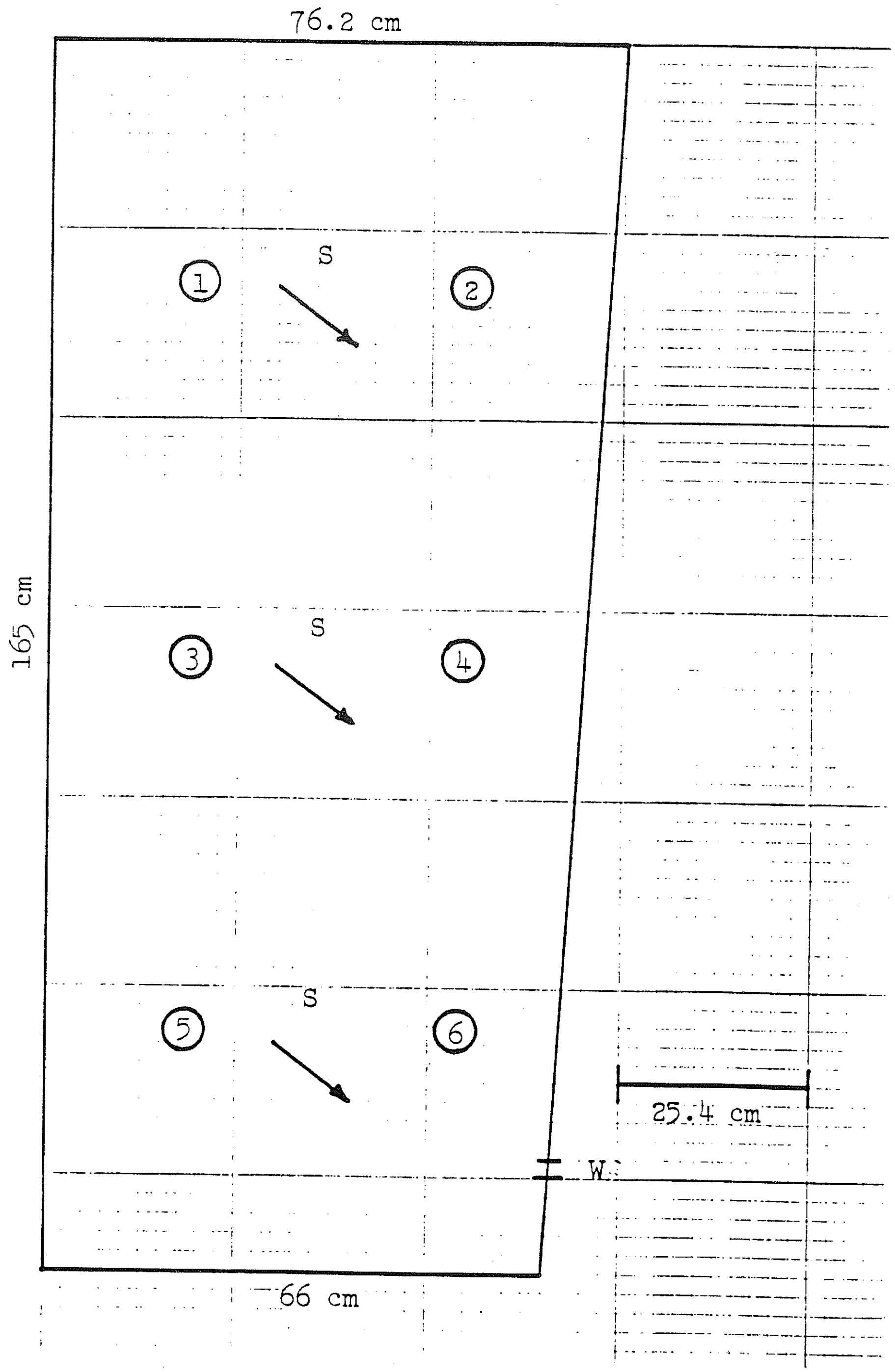

Figure11.--Plot 63 ABJ 105. Rocky, relatively barren plot very sparsely covered with grass, some slight amount of organic matter in the soil was present. Entire plot was seeded with cesium-137 tracer. Direction of drainage is indicated by arrows. Soil samples were taken at locations marked S after tracer experiment had been completed. Water sample taken at location marked W.

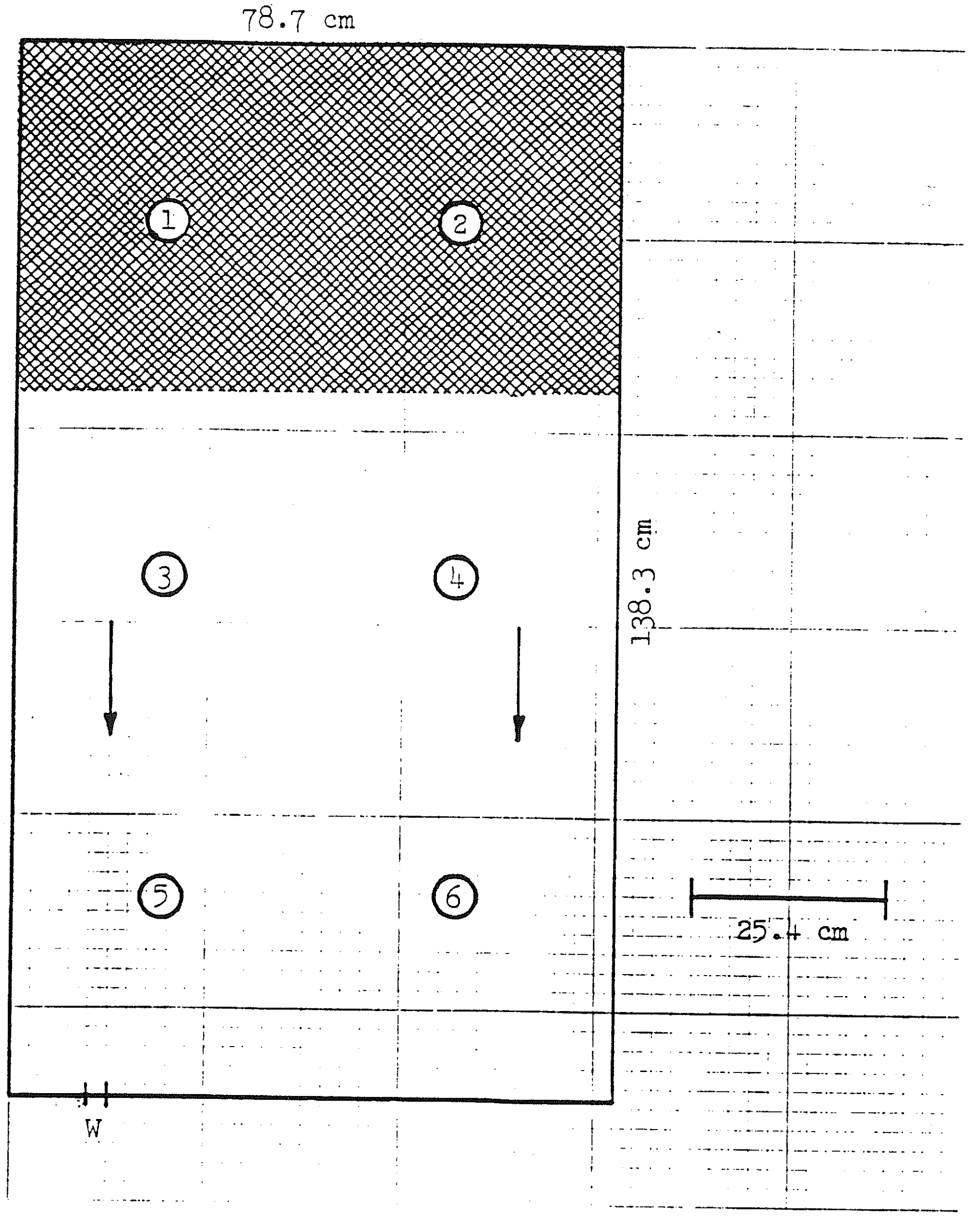

Figure 12.--Plot 63 ABJ 106. Rocky soil near stream. Grass was very sparse on plot and the soil had a relatively low organic content. Direction of drainage indicated by arrows. Only upper third as indicated had cesium-137 tracer applied. Water samples were taken at location marked W.

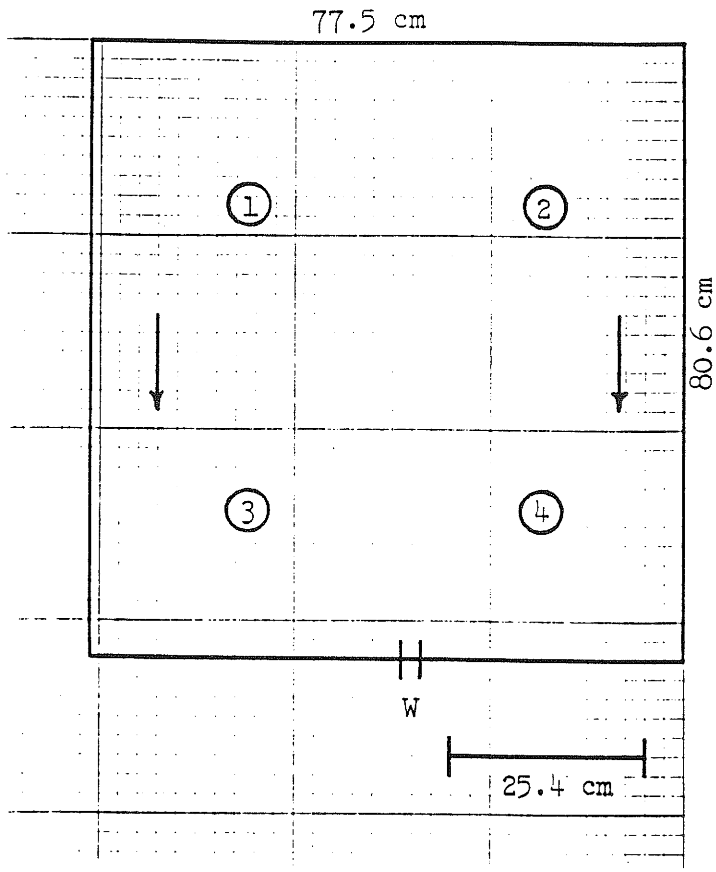

Figure 13.---Plot 63 ABJ 107. Plot in typical tundra, plant cover consisted mostly of grass and small leafy shrubs, soil was mostly humus or peat. Direction of drainage indicated by arrows. Entire plot was seeded with tracer cesium-137. Water samples were taken at location marked W.

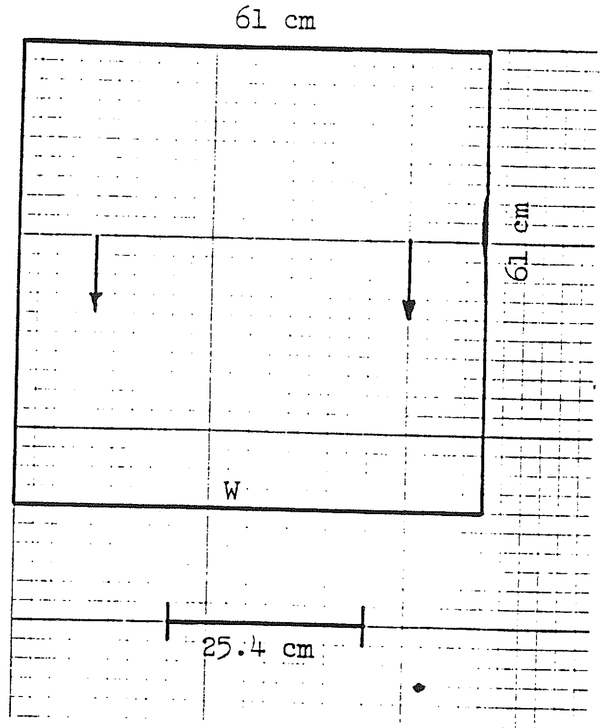

Figure 14.--Plot 63 ABJ 109. Very dense grass 6-10" high, some low shrubbery, and the soil had very high organic content. Direction of drainage indicated by arrows. Entire plot seeded with tracer iodine-131. Water sample taken at location marked W.

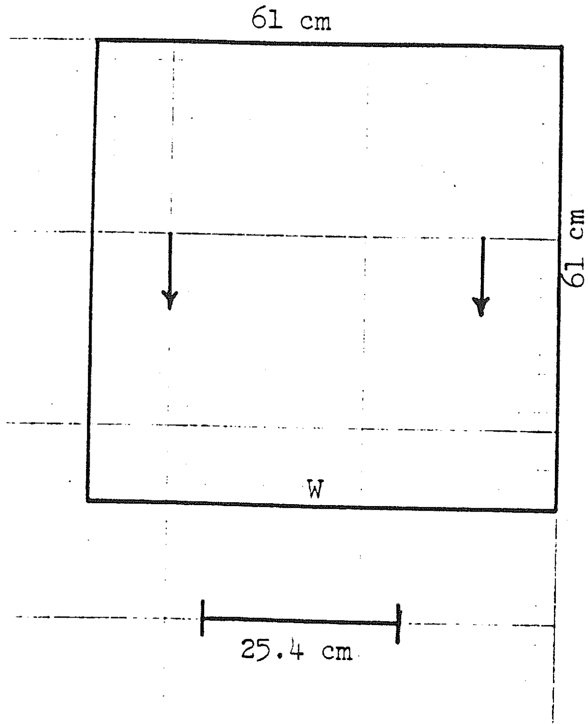

Figure 15.--Plot 63 ABJ 110. Relatively barren plot located on sand bar just above stream level along Snowmass Creek. Direction of drainage indicated by arrows. Entire plot was seeded with tracer iodine-131. Water sample taken at location marked W.

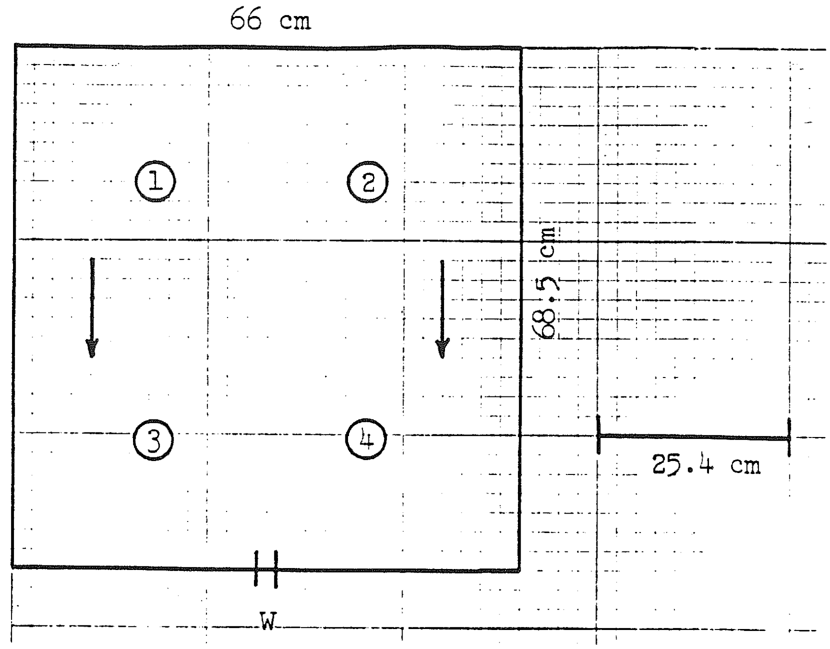

Figure 16.--Plot 63 ABJ 111. Plot was near stream and soil was very rocky with only a relatively sparse cover of grass and no visible humus or peat present. Direction of drainage indicated by arrow. Entire plot was seeded with tracer strontium-85. Water sample taken at location marked with W.

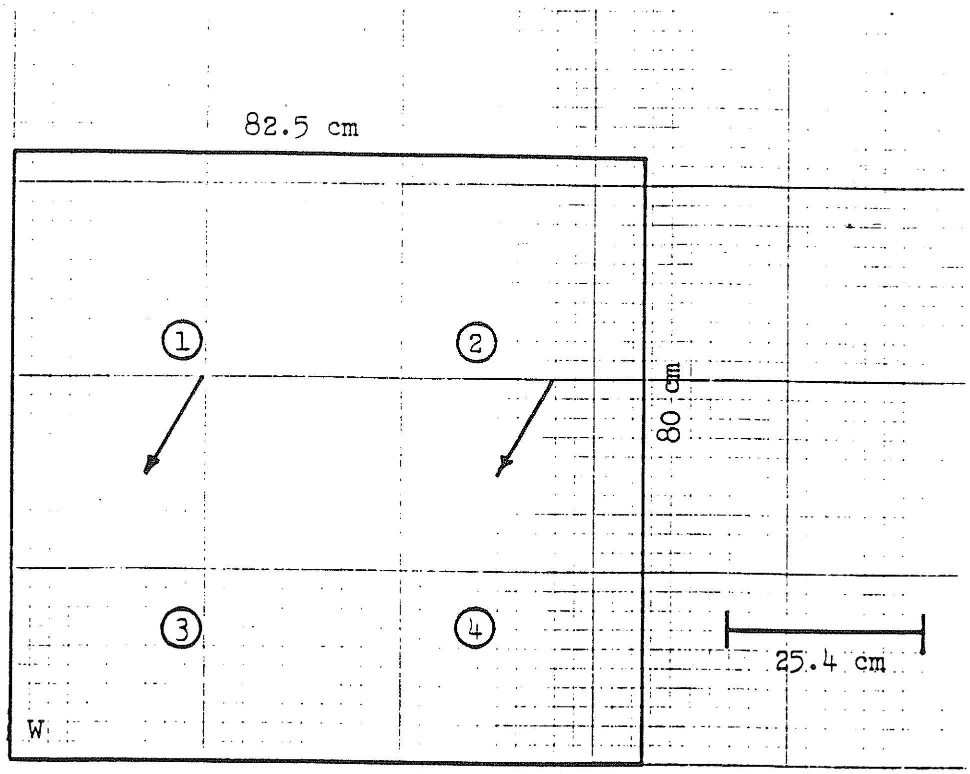

Figure17.--Plot 63 ABJ 112. Plot was on relatively barren rocky soil derived from limestone. Plant cover consisted of very sparse clumps of grass. Direction of drainage indicated by arrows. Entire plot seeded with tracer strontium-85. Water samples taken at location marked W.

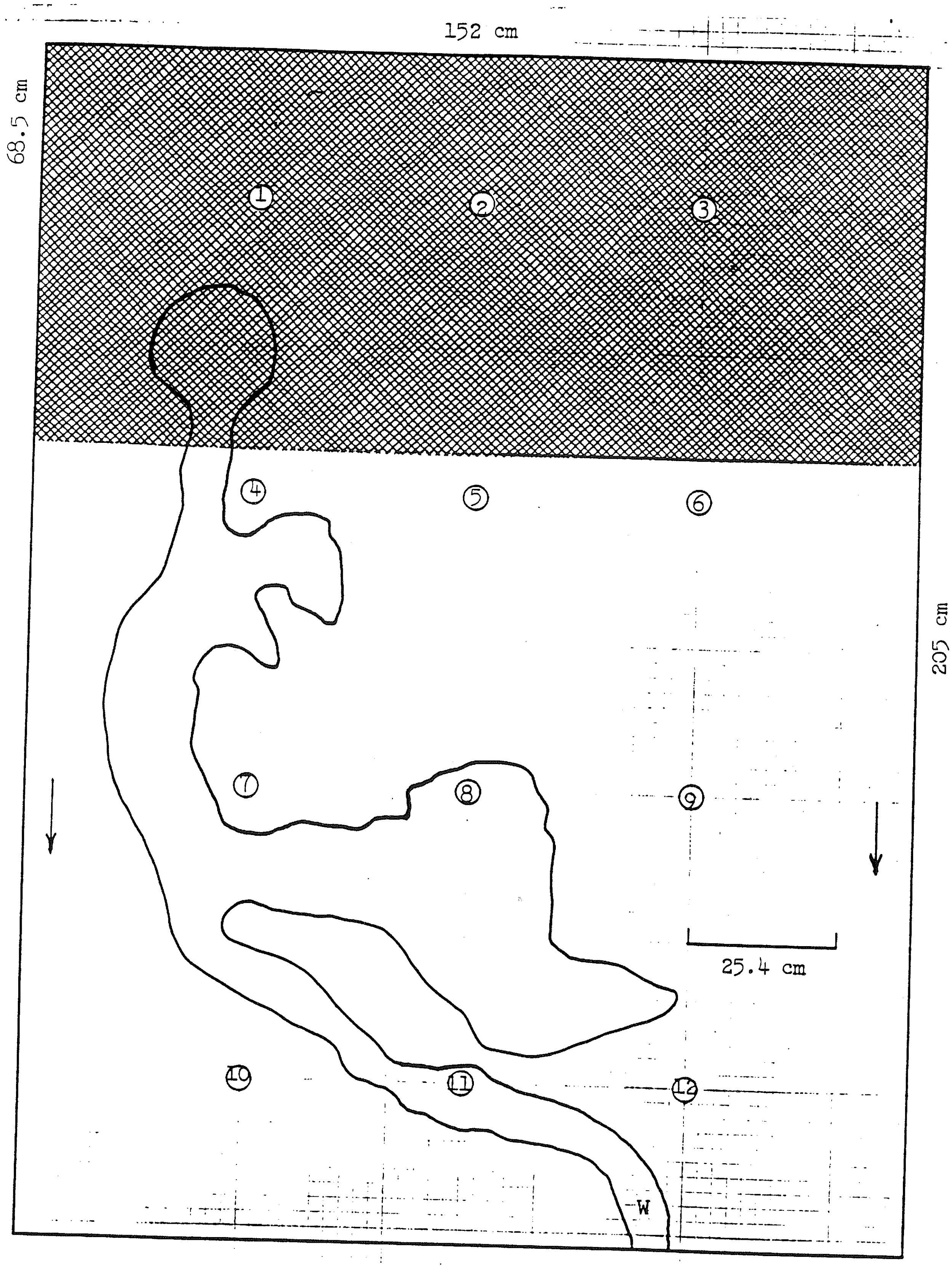

Figure 13.--Plot 63 ABJ 113. Heavy cover of moss and grass with a peat type soil on plot. General direction of drainage indicated by arrows. There was a developed pattern of drainage as indicated by the outline on the plot which had very little plant growth on it. Water samples were taken at the location marked W.

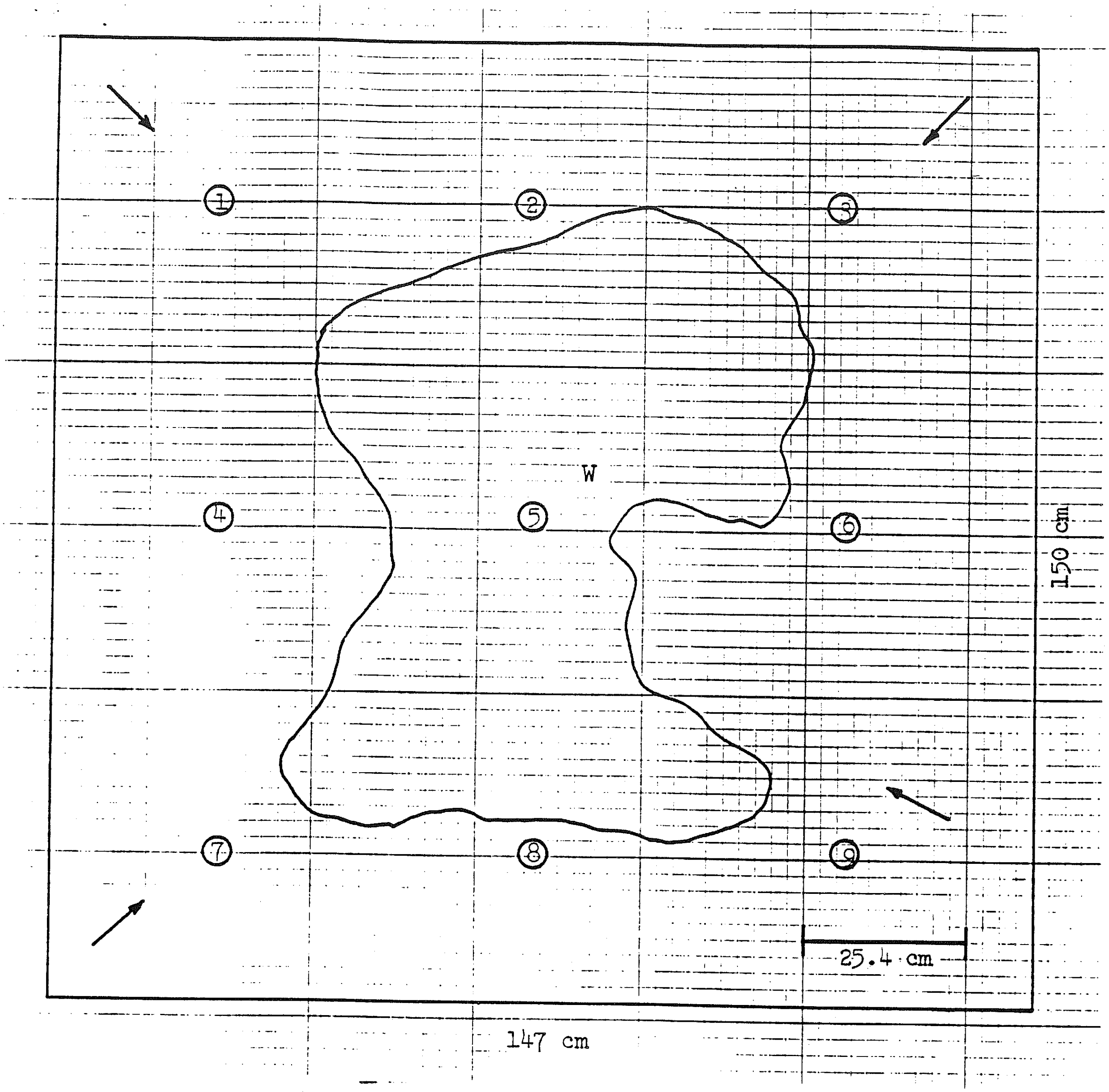

Figure 19.--Plot 63 ABJ 114. Plot had a very heavy cover of moss and grass with a peat type soil. Drainage was toward center depression as indicated by outlined area and arrows. Outlined area was mostly exposed soil with little plant growth. Entire plot was seeded with Sedan event fallout as tracer material.

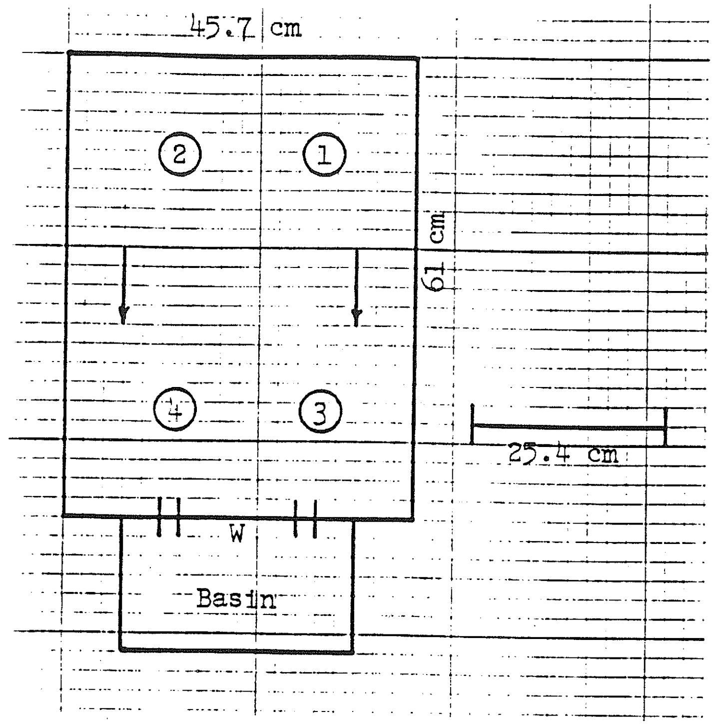

Figure 20.--Plot 63 ABJ 115. Plot was on rocky barren soil. Direction of drainage was toward a collection basin placed as indicated. Entire plot was seeded with Sedan event fallout as tracer. Water samples were collected at location marked W. Soil samples were collected at rain gauge locations 3 and 4.